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EFFECT OF TERRAIN SHAPE AND OBJECT GROUPING ON PERCEPTION OF CHANGE IN ALTITUDE IN A FLIGHT SIMULATOR

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Previous experiments have revealed that three major types of scene elements are perceived in flight simulator visual scenes: (a) texture on the terrain, (b) discrete objects, and (c) terrain shape. Both texture and vertical objects spaced evenly on the terrain have been shown to affect performance of simulated low-altitude flight tasks. Although terrain shape and object grouping affect scene perception, their importance for performanced-based tasks has not been evaluated. The present experiment sought to determine the degree to which terrain shape and object grouping influence detection of altitude change in a flight simulator. Both terrain shape and object grouping were found to have significant positive effects on detection of altitude change. The effects were traced to particular combinations of factors suggesting that relevent information is highly specific in nature. A demonstrated advantage for terrain exhibiting a high density of steeply sloped hills implies that terrain in flight simulators should be rendered with a high degree of accuracy.

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CONTENTS

FIGURES

PREFACE

This effort was conducted at the Armstrong Laboratory, Human Resources Directorate, Aircrew Training Research Division (AL/HRA), in Mesa, AZ, in support of training research and development to maintain air combat readiness and visual scene and display requirements.

This work was performed by the University of Dayton Research Institute (UDRI) under Contract No. F33615-90-C-0005, in support of Work Unit Nos. 1123-03-85, Flying Training Research Support, and 1123-32-03, Tactical Scene Content Requirements. The Laboratory Contract Monitor was Ms Patricia A. Spears, AL/HRA, and Principal Investigator was Dr Elizabeth L. Martin, AL/HRAU. An objective of these work units is to identify flight simulator visual scene content factors that contribute to training effectiveness for low-altitude flight.

We wish to thank Dr Elizabeth L. Martin for helpful comments on an earlier draft of this report.

EFFECT OF TERRAIN SHAPE AND OBJECT GROUPING ON PERCEPTION OF CHANGE IN ALTITUDE IN A FLIGHT SIMULATOR

INTRODUCTION

The content of the artificial visual scene displayed to pilots in flight simulators has been shown to affect performance of a variety of tasks involving flight near the terrain surface including approaches and landings (Barfield, Rosenberg, & Kraft, 1989; Buckland, Monroe, & Mehrer, 1980; Lintern & Koonce, 1991; Lintern & Koonce, 1992; Lintern & Walker, 1991; Reardon, 1988), weapons delivery (Lintern, Sheppard, Parker, Yates, & Nolan, 1989; Lintern, Thomley-Yates, Nelson, & Roscoe, 1987) and low-altitude flight (Buckland, Edwards, & Stevens, 1981; DeMaio, Rinalducci, Brooks, & Brunderman, 1983; Martin & Rinalducci, 1983; McCormick, Smith, Lewandowski, Preskar, & Martin, 1983). The impact that the visual scene has on performance of these flight tasks derives from the important role that vision plays in guiding one's movement within the environment (see, for example, Warren, 1990, for a discussion of issues related to self-motion perception). A very important design question concerns the type and quantity of scene elements required to support visual flight tasks such as those described above. The purpose of the present experiment is to evaluate the impact of several scene content factors on perception of change in altitude, a component of low-altitude flight.

Textured patterns on a flat surface are a rich source of visual information for perceiving and controlling altitude and speed in simulated scenes (Flach, Hagen, & Larish, 1992; Larish & Flach, 1990; and Wolpert, 1988 provide discussions of the relevant literature). Studies conducted in flight simulators also reveal that performance of low-altitude flight tasks is facilitated by the addition of vertical objects to scenes even when scenes already contain texture (Buckland et al., 1981; DeMaio et al., 1983; Kleiss & Hubbard, 1993; McCormick et al., 1983). Nevertheless, the real-world environment appears to present an even richer variety of scene elements than have been manipulated in experiments thus far and a question arises as to whether additional relevant scene properties remain to be identified.

Kleiss (in press a) sought to extend existing knowledge of scene properties relevant for simulating low-altitude flight by first analyzing real-world scenes. The stimuli were videotape segments depicting low-altitude, high-speed flight over a variety of real-world terrains. Experienced pilots rated the degree of similarity between stimulus segments with respect to scene elements important for visual low-altitude flight. Ratings were submitted to a multidimensional scaling (MDS) analysis which revealed that scenes were perceived to vary with respect to two relevant scene properties. The first dimension related to terrain shape which ranged from flat to undulating. The second dimension related to object size and/or spacing which ranged from no objects or vegetation in scenes (i.e., dry lake bed, calm ocean) to large objects or localized regions

of dense vegetation. When flying at low-altitudes, therefore, pilots attend to two major classes of scene properties.

Kleiss (in press b) evaluated the extent to which relevant properties of the real-world environment could be rendered in flight simulator visual scenes. The MDS methodology was repeated in a flight simulator using computer-generated imagery. Results differed somewhat from those obtained with real-world scenes. In particular, evidence pointed to three dimensions rather than two. Dimension 1 was unique to simulated scenes and related to presence or absence of texture on the terrain. This dimension was defined by comparisons involving a control condition used in the flight simulator which consisted of scenes with completely textureless terrain surfaces. Identification of terrain texture as a unique scene property in the flight simulator suggests that texture was so pervasive in the real-world scenes of Kleiss (in press a) that no scenes were perceived to lack it. Dimension 2 related to objects and Dimension 3 related to terrain shape. The property of terrain shape in Dimension 3 was exemplified by scenes containing a high density of steeply-sloped hills which did not extend into the flight path. Results therefore suggest that terrain relief is the important property related to terrain shape rather than large vertical obstructions. Kleiss' (in press b) results provide evidence that scene properties perceived in real-world scenes can be rendered with adequate perceptual fidelity in flight simulators. Indeed, results point to an even richer variety of scene properties than were perceived in real-world scenes.

MDS results are based upon perceptual judgments of similarity between scenes and may not be indicative of information useful for perceiving and controlling altitude. It was therefore deemed important to validate the importance of these scene elements using a performance-based task. Kleiss' (in press b) results point to two scene properties that have not received a great deal of attention in previous investigations of simulated low-altitude flight: One is terrain shape. DeMaio et al. (1983) reported that adding large mountains to simulated scenes so as to define a corridor within which to fly, had no significant effect on the accuracy with which altitude was judged. However, elements of terrain shape in Kleiss' (in press b) experiment were hills which did not extend into the flight path and posed no vertical obstructions. Hills were more indicative of terrain surface relief and this type of information may be more useful for low-altitude flight tasks. Consistent with this hypothesis are the results of Barfield, et al. (1989) who reported that estimates of impact point upon final approach to the runway were more accurate with hills surrounding the runway than with flat terrain. A second finding reported by Kleiss (in press b) was that perception of terrain shape was affected by presence of trees on the terrain, particularly when trees were clustered into groups rather than scattered randomly on the terrain. Terrain surface relief and object grouping will be manipulated in the present experiment to determine their effects on detection of altitude change.

METHOD

Subjects

Four females (mean age = 33 yr, range 25 yr to 42 yr) and eight males (mean age = 28.86 yr, range 18 yr to 43 yr) participated in the experiment. All subjects reported normal or corrected to normal visual acuity. One male subject was an Air Force pilot who had completed undergraduate pilot training but was not currently assigned to an aircraft. Another male subject was a licensed private pilot and instructor. The use of pilots was not intended as a basis for comparison. Whereas pilots respond more quickly and more accurately than nonpilots in tasks involving detection of altitude change, evidence suggests they do not differ with respect to the relative importance of scene content variables (Kleiss & Hubbard, 1991).

Design, Stimuli, and Apparatus

Three factors were varied within subjects: direction of altitude change (C); terrain shape (T); and objects (O). There were two levels of altitude change (C): descent or ascent at 3.05 m/s (10 ft/s). This corresponds to a change of 6.67%/s at an initial altitude of 45.72 m (150 ft, typical of combat missions for jet aircraft) and reflects an intermediate level of detection difficulty (Kleiss & Hubbard, 1993). There were three levels of terrain shape (T): flat, sparse hills, or dense hills. All hills were 22.87 m (75 ft) tall and sloped upward at approximately 13 deg from horizontal. Dense hills were spaced so that there was no intervening flat terrain. Terrain with sparse hills contained approximately 60% fewer hills than that with dense hills and included intervening flat terrain. There were three levels of objects (O): a textured pattern on the terrain surface with no objects; texture plus pine trees spaced evenly on the terrain; and texture plus pine tree clusters. These factors were crossed yielding a total of 18 unique stimulus events.

Imagery was generated by the Advanced Visual Technology System (AVTS, see Eibeck & Petrie (1988) for specifications). Among AVTS's capabilities is cell texturing, a technique by which a complex digitized pattern is replicated on surfaces producing a highly detailed appearance. Texture on the terrain consisted of an irregular pattern of blotches varying in size and luminance. The average luminance of texture sampled across a range of values was 2.001 Cd/m^2. Trees were also modeled using cell texturing. The average luminance of trees sampled across a range of values was 0.637 Cd/m^2. Scenes were back-projected onto three pentagonal screens arrayed horizontally around an F-16 cockpit with nonfunctional controls and instrumentation. Field of view was approximately 210 deg horizontally and 100 deg vertically measured from a viewing distance of 1 m. Responses were entered with a two-button response box held by the subject. Figure 1 shows a scene with dense hills and grouped trees as viewed from the cockpit.

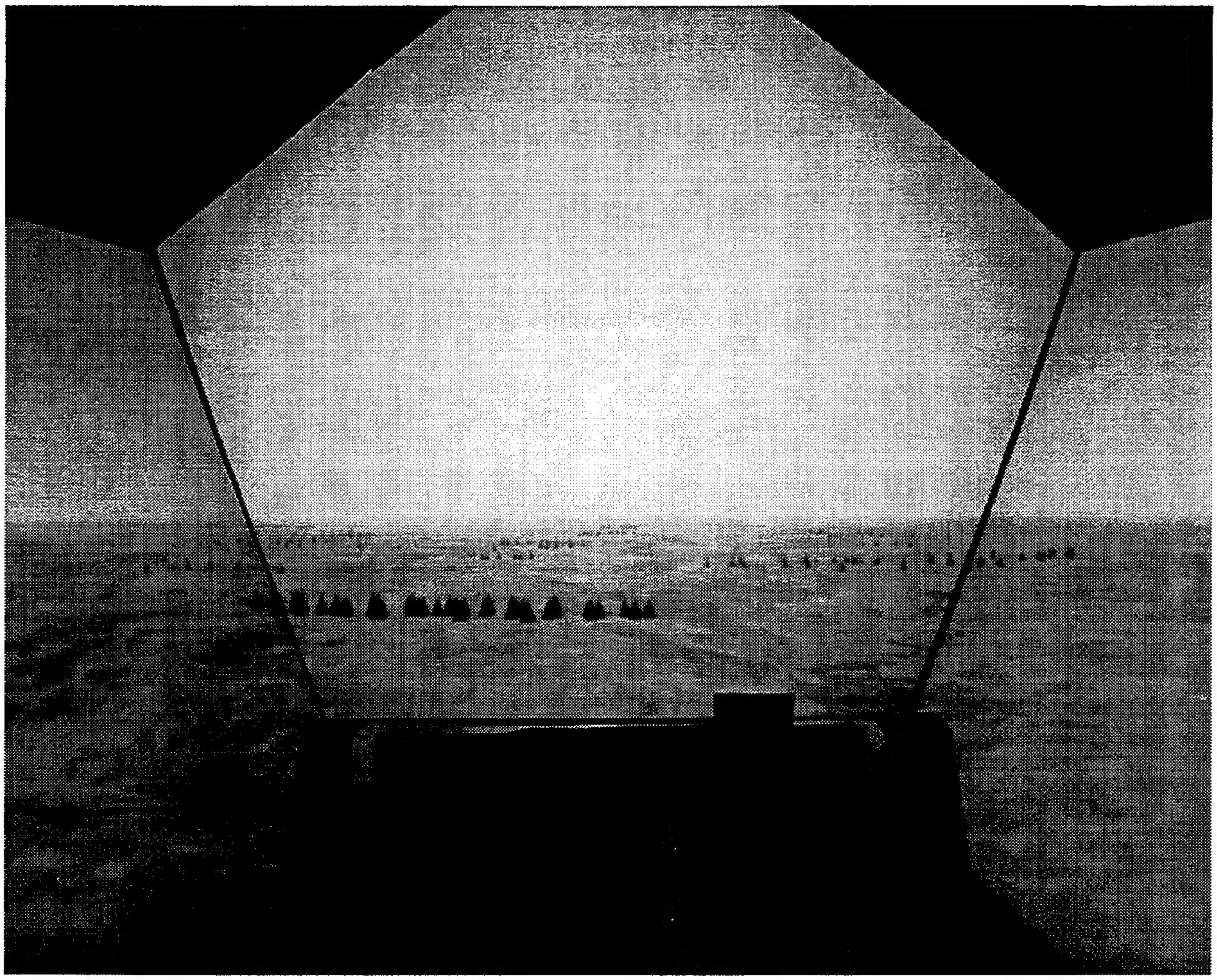

Figure 1
Scene with Dense Hills and Grouped Trees Viewed from the Cockpit

Procedure

The 18 unique stimulus events were presented once randomly within each of eight trial blocks for a total of 144 trials. Each trial began at an altitude of 45.77 m above the terrain and a ground speed of 450 kn, both typical of low altitude combat missions for fighter-type aircraft. Altitude, when hills were present, was relative to the tops of hills so that minimum distance to the terrain was constant across terrain types. Upon onset of each scene, altitude immediately began changing upward or downward and the subject indicated perceived direction of change by pushing one of two buttons on the response box. Pitch remained level throughout the trial eliminating change in the relative position of the horizon as a cue. The display was blanked immediately upon entry of a response and no accuracy feedback was provided. If no response was entered within 6 s of scene onset, the screen was blanked and subjects were asked to enter their best estimate of direction of altitude change. Subjects were encouraged to respond quickly while maintaining highest possible accuracy. Subsequent trials began automatically approximately 6 s after entering a response. A short pause occurred after each block of 18 trials and the entire experiment took approximately 50 min.

RESULTS

Two dependent measures were analyzed: (a) reaction time (RT)-the time to identify direction of altitude change on correct trials; and (b) proportion of correct responses. A log transformation was performed on RT data after adding 1 to each value to ensure all values would be positive.

Figure 2 shows proportion correct for each type of terrain as a function of objects. Accuracy is generally high with the exception of the combination of texture and sparse hills. Data for proportion correct were analyzed using the Catmod Procedure of release 6.00 of the Statistical Analysis System (SAS Institute, Inc., 1989). A logistic modeling approach was used consisting of a subject factor and the main effects and interactions up to and including the three-way interaction of terrain shape (T), objects (O) and direction of altitude change (C). The initial goodness-of-fit test indicated that this model provided an adequate fit of the data ($\chi^2(187) = 192.27$, $p = 0.381$). Further analysis indicated that this initial model could be reduced to one containing only main effects and the single two-way interaction of terrain shape by objects. The reduced model also provided an adequate fit ($\chi^2(195) = 206.33$, $p = 0.275$) without a significant sacrifice in precision as indicated by the change in the maximum likelihood chi-squared statistic ($\chi^2(8) = 14.06$, $p = 0.0802$). The Wald statistics for the various effects in this reduced model indicated that the only significant factors were the subject main effect ($\chi^2(11) = 79.83$, $p < 0.001$),

the change main effect ($\chi^2(1) = 35.59$, $p < .001$) and the terrain shape by objects interaction ($\chi^2(4) = 12.84$, $p = 0.012$). We observed that the probability for a correct response was greater for detecting descent (0.97) than ascent (0.90). The significant two-way interaction appears to reflect lower accuracy for the combination of texture and sparse hills.

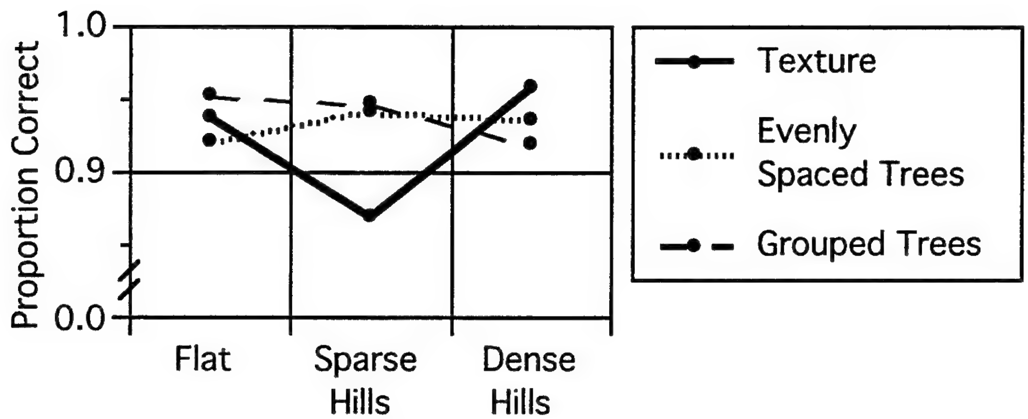

Figure 2
Proportion Correct for Each Type of Object as a Function of Terrain Shape

RT data were submitted to a repeated measures analysis of variance (ANOVA) with terrain shape (T), objects (O), and direction of altitude change (C) serving as factors. Figure 3 shows log correct RT+1 (in seconds) for each level of object as a function of terrain shape on descent and ascent trials respectively. Examination of this figure reveals that detection of descent is particularly quick with grouped trees in combination with dense hills, evenly spaced trees in combination with sparse hills, and texture in combination with sparse hills. Quick detection of descent with texture and sparse hills is accompanied by comparatively slow detection of ascent with this combination of factors. Recall that texture and sparse hills also produced comparatively low accuracy (Fig. 2) suggesting that this combination of factors is not particularly effective. The pattern of differences noted in Figure 3 is supported by a significant three-way interaction (T x O x C, $F(4, 44) = 7.879$, $p < .001$). A more general advantage for scenes with hills is reflected in a significant two-way interaction showing quick detection of descent (T x C, $F(2, 22) = 7.838$, $p = .003$) and a significant main effect (main effect of T, $F(2, 22) = 8.070$, $p = .002$). Quick responding with evenly spaced trees and sparse hills and with grouped trees and dense hills is also reflected in a significant two-way interaction (T x O, $F(4, 44) = 2.967$, $p = .030$) as well as a significant main effect favoring scenes with objects (main effect of O, $F(2, 22) = 3.877$, $p = .036$).

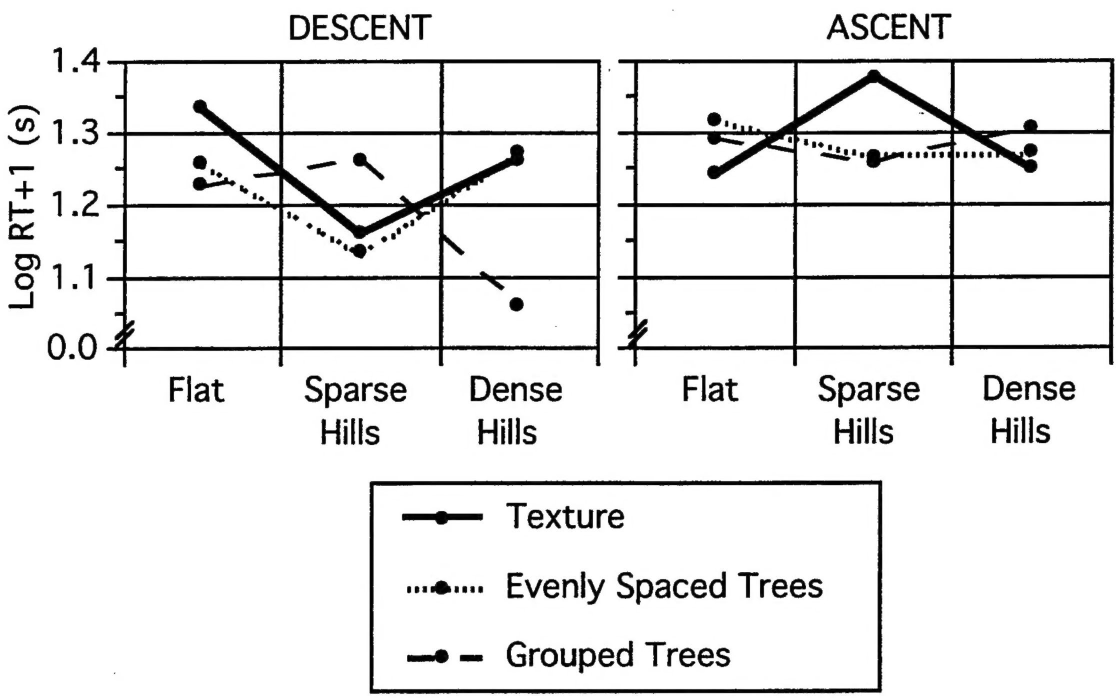

Figure 3
Log Correct RT+1 for Each Type of Objects as a Function of Terrain Shape on Descent and Ascent Trials

DISCUSSION AND CONCLUSIONS

The scenes that yielded best performance contained elements of terrain shape and/or grouped trees. Hence, both of these factors can provide important information for detecting change in altitude. An advantage for scenes with hills, particularly dense hills, is noteworthy because these scenes exhibited a high density of terrain polygons and were very demanding of polygon processing resources. Dense hills, for example, comprised approximately 245 terrain polygons per square nautical mile (excluding trees), a level that could be maintained only over a very limited region of the database due to computer image generator (CIG) processing limitations. Whether this level is sufficient to capture all relevant aspects of terrain shape remains an open question. Present results clearly point to the level of detail at which terrain is rendered as an important consideration in the design of flight simulator visual scenes.

Kleiss and Hubbard (1993) reported that adding vertical objects to scenes that contained a textured pattern on flat terrain produced a consistent improvement in detection of altitude change. No consistent advantage was observed in the present experiment for scenes containing trees compared to scenes containing texture alone. The major difference between present scenes and

those used by Kleiss and Hubbard was the presence of hills and/or grouped trees. This implies that exposure to hills and/or grouped trees on some trials influences performance with texture or evenly spaced trees on other trials. The present design does not allow inferences to be made regarding the direction of this effect. However, a between-subjects manipulation of terrain shape and objects would provide a measure of performance in each condition independent of other conditions. A transfer condition in which exposure to one combination of factors over a series of trials was followed by exposure to another combination of factors would reveal whether there is interference or facilitation between conditions. The possibility of interference is of particular concern as it would indicate a need for specialized training to minimize the interference.

There was no evidence of a consistent difference among levels of terrain shape in the present experiment and this stands in contrast to the MDS results of Kleiss (in press b, Exp. 1, Dim. 3). This fact cannot be attributed to carry-over effects from prior exposure to other scenes because the MDS methodology was based upon repeated presentations of each stimulus. The conclusion, therefore, is that important differences exist between the present experiment and the MDS experiment of Kleiss (in press b). Two possibilities are apparent. Present scenes depicted changing altitude whereas the scenes used by Kleiss (in press b) depicted constant altitude. Researchers have emphasized that perception of one's motion within the environment is mediated by changing geometric relations specific to that motion (see, for example, a discussion by Warren, 1990). It is possible that geometric relations specific to changing altitude dominated perception in the present experiment. A second possibility is that the task of detecting change in altitude draws attention to a different type of information than the MDS rating task of Kleiss (in press b).

These two possibilities could be addressed by combining aspects of the two experiments in a single experiment. For example, the MDS methodology could be used with scenes depicting changing altitude rather than constant altitude. If the dimensional structure differed from that of Kleiss (in press b), the implication would be that geometric relations specific to changing altitude account for the highly specific nature of present results. Conversely, if the dimensional structure were similar to that of Kleiss (in press b), the implication would be that the task of detecting change in altitude draws attention to a different type of information than the MDS rating task.

To summarize, present results provide evidence that both terrain shape and object grouping have a positive effect on detection of altitude change in a flight simulator. However, effects can be highly specific in nature suggesting that what is important in scenes is not the mere presence of certain scene items, but relationships among items. A topic for future experiments will be to identify the specific relationships that are most informative for various flight tasks.

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